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COMPLETION OF PRE-TRIAL PHASE OF DIESEL EMISSIONS REDUCTION OPTION DEVELOPMENT

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1. SUMMARY

A sampling system for the determination of pass-through PAH's and mutagens with the conventional dilution tube has been developed. The sampling system incorporates two polyurethane foam filters (PUF's) installed downstream of the conventional Hi-Vol sampling filter. Effectiveness of the PUF's in collecting the pass-through PAH's was determined with the use of a separate sampling system incorporating an XAD-2 adsorbent cartridge. Three separate test conditions of process blank (background air), neat diesel (without Corning DPF's), and neat diesel with Corning DPF's were used to evaluate the effectiveness of the modified dilution tube.

The Hi-Vol filter collected between 84% to 99% of the individual PAH compounds in the uncontrolled diesel exhaust emissions. With the Corning DPF's installed on the engine the percentage of PAH's collected on the Hi-Vol filter ranged between 37.6% and 92.4% with an average of 78%. Fluoranthene exhibited the greatest tendency to pass-through the Hi-Vol filter. The Corning DPF's reduced the raw exhaust PAH emissions by 90% or better at the steady state engine condition (2200 RPM 7/8 LOAD).

The mutagenic activity of the uncontrolled diesel emissions was 27,338 revertants per cubic meter of raw exhaust with 94% of the mutagenic activity found on the Hi-Vol filter. With the Corning DPF's installed the mutagenic activity of the diesel emissions dropped to 3,660 revertants per cubic meter of raw exhaust resulting in a total mutagenic reduction of 87%. A 5.6% pass-through of mutagens was observed on the PUF's.

2. INTRODUCTION

The sampling and characterization of diesel exhaust emissions has been under constant review and is the subject of optimization studies. Particulates, emitted in the exhaust of diesel engines, are comprised of insoluble and soluble fractions, the latter containing polynucleararomatic hydrocarbon (PAH) compounds. Some of these PAH compounds are known carcinogens and are, therefore, of concern.

Significant advances have been made in the control of diesel exhaust particulate emissions. Exhaust after treatment devices such as ceramic diesel particulate filters (DPF's) are known to trap particulates with an efficiency of around 90%. Although the advances in particulate control technology have been generally laboratory derived, their commercial vehicle application is near. The majority of emissions characterization with the use of DPF's have been carried out under steady state or transient engine operating conditions with little work on the characterization of the products of regeneration. Regeneration is a term describing the oxidation of particulate material accumulated on DPF's or other types of particulate traps.

Dilution tunnels and dilution tubes have generally been used as equipment for the sampling of diesel exhaust particulates. Dilution tunnels accept the complete flow of engine exhaust and a portion of the diluted exhaust is passed through a collection filter. Filters normally used are teflon coated glass fibre. With the dilution tube, a small portion of the exhaust flow is diluted and the complete diluted exhaust flow is passed through a 20 cm by 25 cm high volume sampler (Hi-Vol) filter.

These methods are adequate for collecting particulate emissions from uncontrolled diesel exhaust (i.e. without the use of diesel particulate filters). In the case of particulate controlled diesel exhaust emissions,

however, the reduction of insoluble particulates minimizes the condensation of soluble particulate on the insoluble. It has been theorized, therefore, that the soluble fraction stays in a gaseous or vapour form and passes through the sampling filter. The "pass-through" components may also contain PAH's.

This report summarizes the activities that were carried out to quantitatively determine the pass-through of certain PAH's with the use of a modified dilution tube. The "pass-through" fraction was also analyzed to determine its contribution to results from the Ames mutagenic assay. Tests were carried out to determine background or ambient (also dilution) air conditions prior to engine testing. Baseline engine testing was performed on a Deutz F6L 714 diesel engine operating on No. 1 diesel fuel without the use of diesel particulate filters. Further tests were performed with Corning DPF's installed on the same test engine with the same fuel.

3. SAMPLING SYSTEM DESCRIPTION

The dilution tube, developed under a previous CANMET program, was modified for the determination of "pass-through" PAH's. A section between the high volume filter holder and blower was designed and fabricated. This section was used to hold the polyurethane foam filters (PUF's) downstream of the main sampling filter. Figure 1 gives a schematic of the modified dilution tube sampling system.

A portion of the dilute sample gas is withdrawn downstream of the PUF's and passed through an XAD-2 resin trap. Sample gas flow was regulated using a rotameter and measured using a calibrated, temperature compensated dry gas meter. The total volume sampled with the XAD-2 sampling system was approximately 1% to 1.8% of the total volume sampled with the modified dilution tube. The XAD-2 sampling system was not used in the collection of samples for the Ames mutagenic assay.

Diesel exhaust gases were diluted with air (dyno cell control room air) at an approximate ratio of 16:1. Dilution ratios were determined by measuring the raw exhaust gas carbon dioxide (CO_2) concentration and the dilute CO_2 concentration in the dilution tube. A control valve in the raw exhaust transfer tube was used to regulate the flow of exhaust gas while a total dilute exhaust flow was controlled by adjusting the Hi-Vol blower speed.

Each test constituted the collection of dilute exhaust particulate on a total of eight Hi-Vol filters. Sampling duration for each filter was between 21 to 30 minutes depending on the pressure drop across the sampling filter.

4. TEST CELL EQUIPMENT DESCRIPTION

All tests were conducted using an air-cooled Deutz F6L 714 diesel engine. A Go-Power, DT-1000, flow through water brake dynamometer was used to apply load to the test engine. This dynamometer is attached directly to the flywheel housing. Two oil bath type air cleaners were used in the combustion air stream. Fifteen type 'K' thermocouples were used to measure temperatures at various points on the test engine as shown in Figure 2. Direct temperature readings were taken off a Doric digital trendicator with thermocouple switching capability.

The test engine was operated at 2200 RPM and 7/8 load (373 N.m torque) for each test. No. 1 grade diesel fuel was used for all tests.

Corning ceramic diesel particulate filters were used for the controlled diesel emissions tests. The DPF's, measuring 30 cm in diameter by 30 cm long, were designed for a Deutz F8L 413F/W diesel engine. It was assumed, however, that these slightly oversized DPF's would represent similar operating characteristics to a properly sized unit at steady state engine operating conditions. DPF's were preconditioned prior to each test by operating the engine at full load/speed condition. This preconditioning procedure ensured that full regeneration of the DPF's had taken place.

Engine exhaust backpressures, upstream and downstream of the DPF's, were measured during each test. In all cases, differential exhaust backpressure was not allowed to exceed 15 cm of water.

5. ANALYSIS

5.1 PAH's

XAD-2 resin used for the PAH tests was cleaned prior to sampling. The resin was cleaned by extraction in a Soxhlet apparatus for 20 hours using spectroscopic grade cyclohexane. A rotary evaporator was then used to evaporate the cyclohexane extract to dryness under reduced pressure at a temperature of 30°C. The dryed residue was then dissolved in 5 to 10 mL of methanol, and a sample injected into a high performance liquid chromatograph (HPLC) for the quantitative determination of the following PAH compounds:

- fluoranthene (F)
- benzo[a]anthracene (B[a]A)
- benzo[k]fluoranthene (B[k]F)
- benzo[a]pyrene (B[a]P)
- dibenz[ah]anthracene (DiBenz[ah]A)

and
- benz[ghi]perylene (Benz[ghi]Per).

The following HPLC conditions were used for the determination of the PAH compounds:

- Injection Volume : 50 µL
- Column : C_{18} RP Ultrasphere ODS
- 4.6 mm x 25 cm
- Gradient Program : 50% CH_3CN -100% CH_3CN in 50 min. Hold at 100% CH_3 for 15 min. 100% CH_3CN 50% CH_3CN in 10 min.
- Flow Rate : 1.00 mL/min

• Detector	:	Fluorescence, λex 280 nm λam 389 nm. Sensitivity 5.61 Attenuation 0.5 μA.
• Pressure	:	190-1850 psi
• Data System	:	SP-4100 computing Integrator
• Chart Speed	:	0.5 cm/min
• Temperature	:	Ambient

Samples of extracts from the cleaning of the XAD-2 resin were analyzed to ensure that impurities did not interfere with sample analysis. HPLC chromatograms for the process blank and test samples are presented in Appendix A.

Polyurethane foam filters were also cleaned prior to sampling. Several extractions of the PUF's with cyclohexane were necessary prior to obtaining clean filters.

Following sampling, the XAD-2 resin and glass wool support were removed from their container and extracted for 8 hours. Samples were extracted with cyclohexane in a Soxhlet apparatus. The PUF plugs were cut into small sections and extracted in a Soxhlet apparatus for 8 hours with cyclohexane. Hi-vol filters were extracted for 12 hours in dichloromethane in a Soxhlet apparatus.

Individual cyclohexane and dichloromethane extracts were evaporated to dryness on a rotary evaporator under reduced pressure at a temperature of 35°C. The resultant residue was dissolved in 2 mL of methanol and a sample of the methanol solution injected into the HPLC.

5.2 Ames Salmonella Mutagenicity Assay

Three sets of Hi-Vol filters and polyurathane foam plugs were assayed for mutagenicity using the Ames Salmonella mutagenicity assay. The Salmonella tester strain used was TA-98 in the absence of metabolic activation. The three samples were 1) Blank Dilution Air, 2) Raw Diesel Exhaust and 3) Diesel plus the Corning Filter Traps. The Hi-Vol filters and PUF (polyurathane foam plugs) were extracted for 16 hr with dichloromethane (DCM). The solvent was then taken to dryness and the weight of the soluble organic fraction (SOF) determined. The samples were then dissolved in dimethyl sulfide (DMSO) at a concentration of 200 µg/mL and submitted for testing in the Ames Salmonella mutagenicity assay. Testing was carried out between 0 and 1000 µg per plate to obtain dose-response data. The specific activity as revertants/µg was calculated for each of the samples from the linear portion of the dose response curve.

6. TEST RESULTS

Selected Hi-Vol filters were analyzed to determine the soluble and insoluble fractions of the total particulate material. For tests carried out on uncontrolled engine emissions the soluble fraction accounted for approximately 44% of the total particulate (see Table 1). With the Corning DPF's installed the soluble fraction averaged 65% of the total particulate. Table 2 gives the volumes sampled for the XAD-2 and dilution tube sampling systems. Particulate loadings for the three test conditions are also presented in Table 2. Based on neat diesel and neat diesel with DPF tests the total particulate control efficiencies averaged 80% and 93%.

Table 3 gives the average temperature measurements for each test condition. Thermocouple identifications are given in Figure 2. Table 4 gives the engine exhaust backpressure data recorded for each sample filter (total 8 sample filters) for the three test conditions.

6.1 PAH's

The XAD-2 cartridge, PUF plugs, and Hi-Vol filters were analyzed for the 6 PAH's for the process blank, neat diesel, and neat diesel with Corning DPF's. Table 5 gives the sample mass of PAH's analyzed at the three points in the modified dilution tube sampling system. The HPLC method sensitivities (lower detection limits) for the 6 PAH compounds are given in Table 6. Variations in the method sensitivity for a given PAH compound are due to variations in the sample dilutions.

Concentrations of PAH's in the raw diesel exhaust (corrected for dilution ratio) are presented in Table 7. Minor quantities of 5 of the 6 PAH compounds were found in the process blank (i.e. no diesel exhaust entering the dilution tube). These data suggest that the dilution air does not contribute a sampling artifact to the results found with diesel exhaust entering the dilution tube.

In the case of uncontrolled diesel exhaust emissions the majority of the PAH compounds were found on the Hi-Vol sampling filter. The Hi-Vol sampling filters collected between 84.4% and 99.3% of the total individual PAH compounds measured at the three locations in the dilution tube. Polyurethane foam filters collected 9.7% of the pass-through fluoranthene and 13.1% of pass-through benzo[a]anthracene. Minimal quantities of benzo[K]fluoranthene and benzo[a]pyrene (i.e. < 2.7%) were found on the PUF's. Also, minimal quantities of PAH compounds were found on the XAD-2 resin traps. These data show that the polyurethane foam filters are reasonably efficient in collecting the minimal quantities of PAH's that pass-through the Hi-Vol sampling filter.

Concentrations ($\mu g/m^3$) of PAH's are significantly lower when the Corning DPF's are installed on the Deutz F6L 714 engine exhaust. The most significant pass-through was observed for fluoranthene where 49% was found in the XAD-2

resin. This result is somewhat similar to that found in the process blank (52%). It is assumed, therefore, that fluoranthene exhibits a high propensity to adsorb onto diesel particulate matter. The polyurethane filters were efficient in collecting (1% to 18%) of the 5 other PAH compounds that passed through the Hi-Vol sampling filter.

Table 8 shows that there is a slightly higher pass-through of PAH's for test conducted with the Corning DPF's. Although the percentage pass-through is greater, the quantities of PAH's found in all three locations are significantly lower than for tests without the Corning DPF's. PAH collection efficiencies were determined at 90% or better.

6.2 Ames Mutagenic Assay Results

Table 10 gives results of the particulate distribution for the three test conditions of process blank, neat diesel, and neat diesel with Corning DPF's. Total particulate concentration was 89.3 mg/m^3 for neat diesel as measured on the Hi-Vol filter. A pass-through of 10.9 mg/m^3 was found on the PUF's. Soluble organic fraction accounted for 39.9% of the total particulate on the Hi-Vol filter and 76.2% on the PUF's. The Hi-Vol filter collected 81.2% of the total soluble material with 18.8% collected on the PUF's.

The total particulate concentration was 6.2 mg/m^3 as determined with the Hi-Vol filter for engine operation with the Corning DPF's installed. A further 5.3 mg/m^3 of total particulate material was found on the PUF's under the same test conditions. The soluble particulate fraction accounted for 60.0% of the total particulate material on the Hi-Vol filter and 64.0% on the PUF's. Based on these data, the total particulate collection efficiency for the Corning DPF's is 89% and 84% for soluble particulate

Ames Salmonalla mutagenicity assay results are presented in Table 2. The process blank produced a specific activity of 0.073 revertants per microgram

of soluble particulate on the Hi-Vol filter. A negative mutagenic response was determined for the soluble fraction collected on the PUF's. The mutagenic contribution of the process blank to diesel emission test results is negligible.

A specific mutagenic activity of 0.72 revertants per microgram of soluble particulate was found on the Hi-Vol filter from the neat diesel tests (i.e. without Corning DPF's). This revertant concentration results in a concentration of 25,704 revertants per cubic meter of raw exhaust. The specific activity of the soluble fraction collected with the PUF's was significantly lower at 0.19 resulting in 1,634 revertants per cubic meter of raw diesel exhaust. Therefore, six percent of the total mutagenic activity was attributable to pass-through mutagens.

In the case of tests carried out with the Corning DPF's installed, the specific activity (0.96) was higher than the neat diesel test. However, since the soluble concentration is lower, the revertants per cubic meter of exhaust is only 3,456. The specific activity on the PUF's was very low at 0.06 revertants per microgram of soluble particulate. The total pass-through mutagens accounted for 5.6% of the total mutagenicity. An overall reduction in the total mutagenicity of 87% can be attributed to the effective control efficiency of the Corning DPF's

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TABLE I

Soluble & Insoluble
Particulate Data for PAH Tests

Test 2, Neat Diesel Filter #	Condition RPM/lb.ft.	Insoluble Fraction (%)	Soluble Fraction (%)	Total Weight (mg)	PUF plugs Wt (mg)
1	2200/275	57.4	42.6	90.3	41.0
2	2200/275	60.1	39.9	87.4	
3	2200/275	54.1	45.9	84.4	
4	2200/275	54.2	45.8	80.2	
5	2200/275	57.9	42.1	83.8	
6	2200/275	55.7	44.3	75.7	
7	2200/275	45.3	54.7	79.0	
8	2200/275	61.3	38.7	86.9	
Test 3, Neat Diesel with Corning DPF's					
1	2200/275	34.9	65.1	12.9	117.0
2	2200/275	49.0	51.0	14.7	
3	2200/275	47.1	52.9	14.0	
4	2200/275	53.8	46.2	13.2	
5	2200/275	26.3	73.7	9.9	
6	2200/275	39.6	60.4	9.1	
7	2200/275	20.0	80.0	8.0	
8	2200/275	10.0	90.0	8.0	

TABLE II

Particulate Loadings
and
Sample Volumes

	Process Blank		Neat Diesel		Neat Diesel with DPF's	
	XAD-2	PUF & Filter	XAD-2	PUF & Filter	XAD-2	PUF & Filter
Test 1 (PAH)	3.363 m^3	188.41 m^3				
Loading (mg/m^3)		0.261 (.116)*				
Test 2 (PAH)			2.228 m^3	143.85 m^3		
Loading (mg/m^3)				85.23 (80.30)		
Test 3 (PAH)					2.014 m^3	207.69 m^3
Loading (mg/m^3)						17.38 (7.13)
Test 1 (AMES)	-	210.04 m^3				
Loading (mg/m^3)		0.188 (.136)				
Test 2 (AMES)			-	146.53 m^3		
Loading (mg/m^3)				100.12 (89.26)		
Test 3 (AMES)					-	207.67 m^3
Loading (mg/m^3)						11.50 (6.18)

* Loading Based on Particulate Collected on Hi-Vol Filters Only.

TABLE III

Temperature Measurement Summary

Thermocouple #	PAH TESTS			AMES TESTS		
	Test 1 Process Blank (°C)	Test 2 Neat Diesel (°C)	Test 3 Neat Diesel With DPF's (°C)	Test 1 Process Blank (°C)	Test 2 Neat Diesel (°C)	Test 3 Neat Diesel With DPF's (°C)
1	425	452	423	423	428	427
2	449	477	452	450	452	461
3	444	474	448	448	446	454
4	432	453	440	429	432	444
5	427	-	-	-	-	-
6	442	464	444	439	445	446
7	445	474	415	446	448	422
8	458	483	417	454	462	420
9	21	29	24	15	25	25
10	49 (Room Temp)	56 (Room Temp)	417	57 (Room Temp)	50 (Room Temp)	423
11	45 (Room Temp)	51 (Room Temp)	402	52 (Room Temp)	45 (Room Temp)	404
12	28	46	45	31	43	44
13	25	28	27	29	25	27
14	194	207	205	196	224	210
15	90	96	94	94	90	95

*Use legend page for thermocouple numbers

TABLE IV

Engine Exhaust Backpressure Data (cm H_2O)

Test No.	Location	Sampling Filter Number 1	2	3	4	5	6	7	8
		PAH TESTS							
1. Process Blank	Left Exhaust	14.2	14.2	14.6	14.6	14.2	15.2	15.8	14.0
1. Process Blank	Right Exhaust	9.1	8.8	8.4	8.8	9.0	9.6	11.0	9.8
2. Neat Diesel	Left Exhaust	11.4	11.6	13.2	13.4	13.4	12.6	15.8	16.6
2. Neat Diesel	Right Exhaust	9.8	9.6	9.8	10.0	10.2	10.0	10.4	11.2
3. Neat Diesel w DPF's	Before Left DPF	21.7	22.5	23.6	24.0	24.7	25.6	26.4	27.6
3. " " " " " "	After Left DPF	9.4	9.4	9.4	9.4	9.4	9.2	9.3	9.2
3. " " " " " "	Before Right DPF	25.0	26.6	28.2	29.5	30.9	31.8	32.7	34.2
3. " " " " " "	After Right DPF	8.1	9.9	12.4	10.6	9.2	6.0	7.9	9.4
		AMES TESTS							
1. Process Blank	Left Exhaust	18.2	18.2	18.2	19.0	18.2	18.2	17.8	15.0
1. Process Blank	Right Echaust	10.6	11.0	11.2	11.8	12.0	11.2	11.2	9.9
2. Neat Diesel	Left Exhaust	13.2	13.8	13.8	14.4	14.2	13.0	13.2	14.6
2. Neat Diesel	Right Exhaust	10.2	10.0	10.2	10.4	10.4	9.6	10.2	10.2
3. Neat Diesel w DPF's	Before Left DPF	25.2	27.8	29.2	31.0	23.4	25.0	27.0	29.1
3. " " " " " "	After Left DPF	9.0	9.0	9.0	9.2	9.0	9.0	9.0	9.1
3. " " " " " "	Before Right DPF	32.5	35.4	37.6	40.6	32.2	34.8	36.6	39.0
3. " " " " " "	After Right DPF	9.2	6.6	8.6	11.4	7.1	12.6	8.8	12.2

TABLE V

Sample Mass (μg) of PAH's Analyzed in Sampling System

PAH	Process Blank			Neat Diesel			Neat Diesel with DPF's		
	XAD-2 Cartridge	PUF Plugs	Filter	XAD-2 Cartridge	PUF Plugs	Filter	XAD-2 Cartridge	PUF Plugs	Filter
F	0.0296	1.289	0.227	0.0206	4.541	41.053	0.0299	0.8366	2.360
B[a]A	0.0086	0.343	0.100	0.0136	4.677	30.020	ND	4.7902	4.262
B[k]F	0.0014	0.0030	0.084	ND	0.3885	15.455	ND	0.2198	2.041
B[a]P	0.0036	0.0979	0.082	ND	1.5726	58.294	ND	0.2248	6.273
Dibenz[ah]A	ND*	ND	ND	ND	ND	9.041	ND	ND	ND
Benz[ghi]Per	ND	0.1081	0.123	ND	0.4365	118.050	ND	ND	14.458

* None detected

TABLE VI

Method Sensitivity (μg) for PAH Analysis

PAH	Process Blank			Neat Diesel			Neat Diesel with DPF's		
	XAD-2 Cartridge	PUF Plugs	Filter	XAD-2 Cartridge	PUF Plugs	Filter	XAD-2 Cartridge	PUF Plugs	Filter
F	0.0024	0.0241	0.032	0.0024	0.0482	1.000	0.0024	0.0482	0.080
B[a]A	0.0020	0.0198	0.024	0.0020	0.0396	0.750	0.0020	0.0396	0.060
B[k]F	0.0013	0.0135	0.014	0.0013	0.0270	0.437	0.0013	0.0270	0.035
B[a]P	0.0030	0.0518	0.062	0.0030	0.1036	1.937	0.0030	0.1036	0.155
Dibenz[ah]A	0.0033	0.0330	0.038	0.0033	0.0660	1.187	0.0033	0.0660	0.095
Benz[ghi]Per	0.0097	0.0967	0.116	0.0097	0.1934	3.625	0.0097	0.1934	0.290

TABLE VII

Concentration ($\mu g/m^3$) of PAH in Diesel Exhaust

PAH	Process Blank			Neat Diesel			Neat Diesel with DPF's		
	XAD-2 Cartridge	PUF Plugs	Filter	XAD-2 Cartridge	PUF Plugs	Filter	XAD-2 Cartridge	PUF Plugs	Filter
F	0.0088	0.0068	0.0012	0.1600	0.5461	4.9372	0.2449	0.0665	0.1875
B[a]A	0.0026	0.00182	0.00053	0.1056	0.5625	3.6103	<0.0164	0.0794	0.3386
B[k]F	0.00042	0.000016	0.00044	<0.0101	0.0467	1.8587	<0.0011	0.0175	0.1621
B[a]P	0.0011	0.00052	0.00044	<0.0233	0.1891	7.0107	<0.0246	0.0178	0.4984
Dibenz[ah]A	<0.00098*	<0.00018	<0.00020	<0.0256	<0.0079	1.0873	<0.0270	<0.0052	<0.0075
Benz[ghi]Per	<0.00288	0.00057	0.00065	<0.0753	<0.0232	14.1972	<0.0794	<0.0154	1.1486

* These values obtained using the lower detection limit and dilution ratio.

TABLE VIII

PAH Distribution in the Modified Dilution Tube Sampling System

PAH	Process Blank			Neat Diesel			Neat Diesel with DPF's		
	XAD-2 Cartridge	PUF Plugs	Filter	XAD-2 Cartridge	PUF Plugs	Filter	XAD-2 Cartridge	PUF Plugs	Filter
F	52.4%	40.5%	7.1%	2.8%	9.7%	87.5%	49.1%	13.3%	37.6%
B[a]A	52.5%	36.8%	10.7%	2.5%	13.1%	84.4%	3.8%*	18.3%	77.9%
B[k]F	48.0%	1.8%	50.2%	0.5%*	2.4%	97.0%	0.6%*	9.7%	89.7%
B[a]P	53.4%	25.2%	21.4%	0.3%*	2.6%	97.1%	4.5%*	3.3%	92.2%
Dibenz[ah]A	-	-	-	2.3%*	0.7%*	97.0%	-	-	-
Benz[ghi]Per	70.2%*	13.9%	15.9%	0.5%*	0.2%*	99.3%	6.4%*	1.2%*	92.4%

*Percentages obtained using lower detection limit values

TABLE IX

Corning DPF Collection Efficiency for PAH's

PAH COMPOUND	Neat Diesel Total $\mu g/m^3$	Neat Diesel with DPF's Total $\mu g/m^3$	Corning DPF Collection Efficiency For PAH's
Fluoranthene	5.6433	0.4989	91%
Benzo (a) anthrancene	4.2784	0.4344	90%
Benzo (k) fluoranthene	1.9155	0.1807	91%
Benzo (a) pyrene	7.2231	0.5408	93%
Di benz (ah) anthrancene	1.1208	<0.0397	>96%
Benz (ghi) perylene	14.2957	1.2434	91%

TABLE X

Particulate Distribution - Results for the Ames Test

	Process Blank		Neat Diesel		Neat Diesel with Corning DPF's	
	Hi-vol filter	PUF's	Hi-vol filter	PUF's	Hi-vol filters	PUF's
*Total particulate mg/m^3	0.136	0.0520	89.3	10.9	6.2	5.3
Soluble particulate mg/m^3	0.128	0.0657	35.7	8.3	3.6	3.4
Insoluble particulate mg/m^3	0.008	0	53.6	2.6	2.6	1.9
% Soluble of total particulate	93.7	100	39.9	76.2	60.0	64.0
% Soluble collected on hi-vol filters	66.0		81.2		51.3	
% Soluble collected on PUF's		34.0		18.8		48.7
Dilution Ratio	-		16.0:1		16.8:1	

* Concentrations are corrected for dilution ratio to raw exhaust concentrations.

TABLE XI

Ames Salmonella Mutagenicity Assay Results

	Process Blank		Neat Diesel		Neat Diesel with Corning DPF's	
	Hi-vol filter	PUF's	Hi-vol filter	PUF's	Hi-vol filter	PUF's
Specific Activity Revertants/ µg of soluble particulates	0.073	-	0.72	0.19	0.96	0.06
*Revertants/m^3	9.34	-	25704	1634	3456	204
*Total Mutagenicity in Revertants/m^3	9.34		27338		3660	
% Mutagenicity on Hi-vol filters	100%		94.0		94.4	
% Mutagenicity on PUF's		0		6.0		5.6

* Corrected for dilution ratio to raw diesel exhaust concentrations.

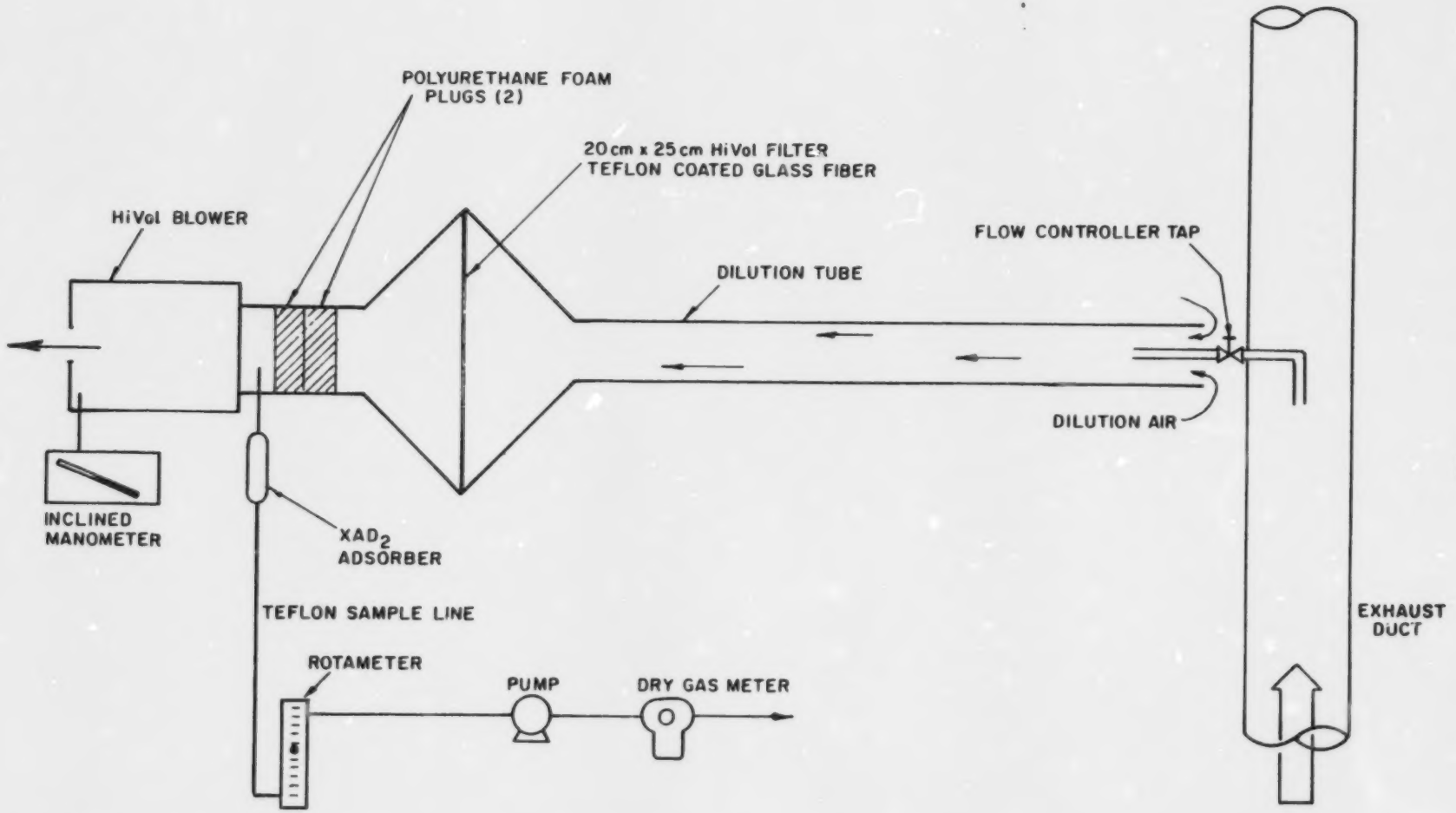
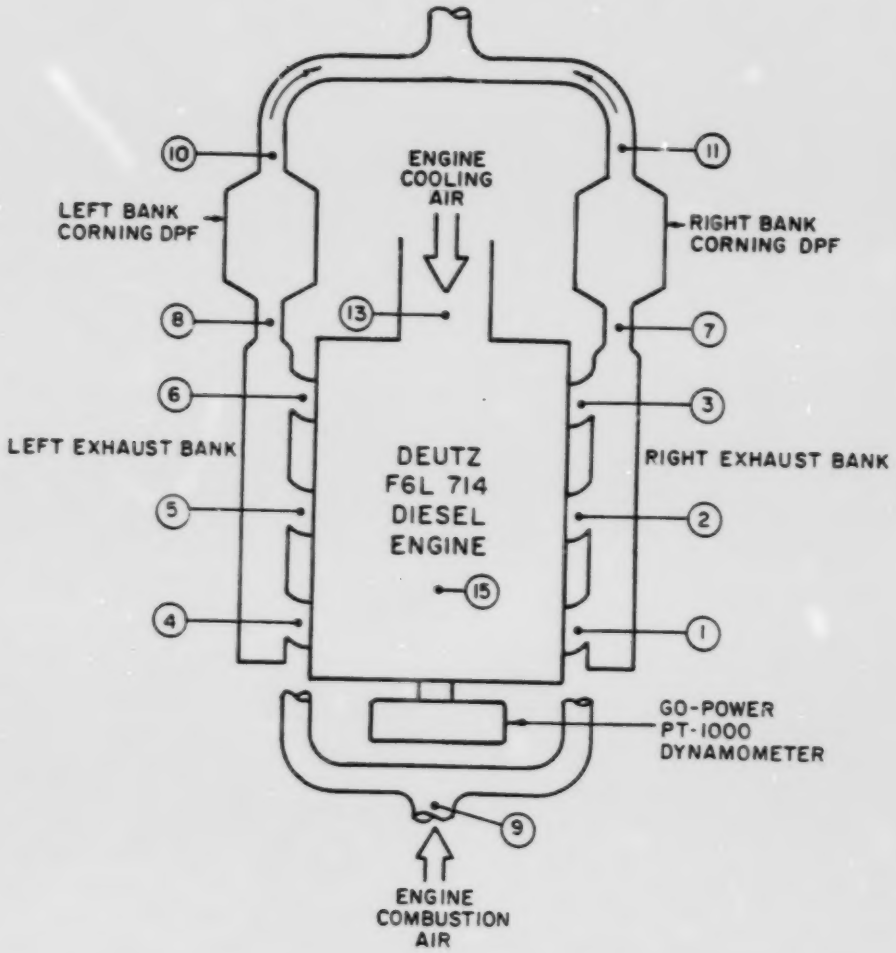


FIG. 1 MODIFIED DILUTION TUBE SAMPLING SYSTEM SCHEMATIC



THERMOCOUPLE No.	LOCATION
1	EXHAUST TEMPERATURE CYLINDER No.
2	" " " "
3	" " " "
4	" " " "
5	" " " "
6	" " " "
7	EXHAUST TEMPERATURE BEFORE LEFT DPF
8	" " " RIGHT DPF
9	COMBUSTION AIR TEMPERATURE
10	EXHAUST TEMPERATURE AFTER LEFT DPF
11	" " " RIGHT DPF
12	DILUTION TUBE TEMPERATURE
13	ENGINE COOLING AIR TEMPERATURE
14	EXHAUST TRANSFER TUBE TEMPERATURE
15	ENGINE CRANKCASE OIL TEMPERATURE

FIG. 2 SCHEMATIC OF ENGINE SETUP AND IDENTIFICATION OF THERMOCOUPLE LOCATIONS.

APPENDIX "A"

HPLC Chromatograms

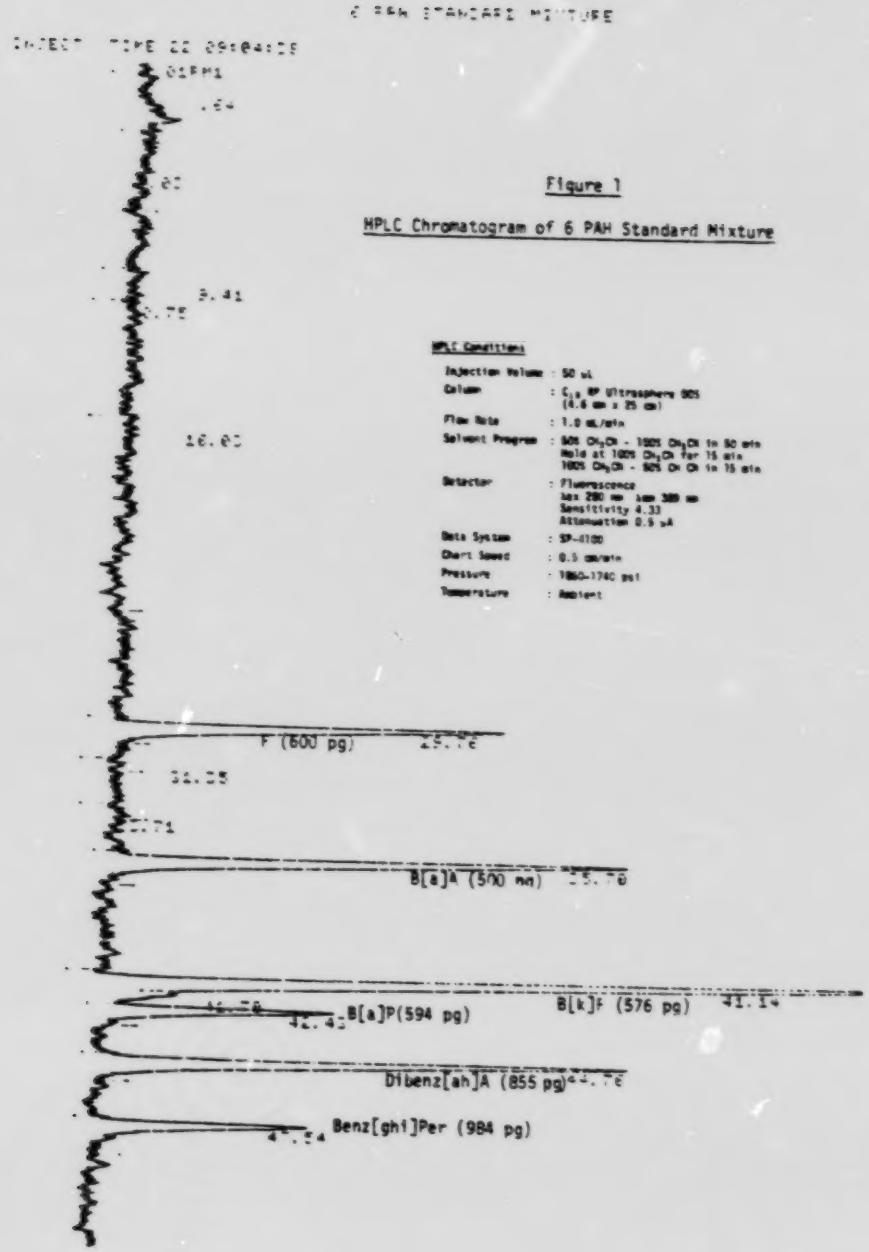


Figure 1

HPLC Chromatogram of 6 PAH Standard Mixture

HPLC Conditions:

Injection Volume	: 50 uL
Column	: C_{18} BP Ultrasphere ODS (4.6 mm x 25 cm)
Flow Rate	: 1.0 mL/min
Solvent Program	: 60% CH_3CN - 100% CH_3CN in 30 min Hold at 100% CH_3CN for 15 min 100% CH_3CN - 60% CH_3CN in 15 min
Detector	: Fluorescence λ_{ex} 280 nm λ_{em} 389 nm Sensitivity 4.33 Attenuation 0.5 uA
Data System	: SP-4100
Chart Speed	: 0.5 cm/min
Pressure	: 1860-1740 psi
Temperature	: Ambient

FIGURE 2

HPLC Chromatogram of PUF Extract - Second Set

(HPLC Conditions same as Fig. 1)

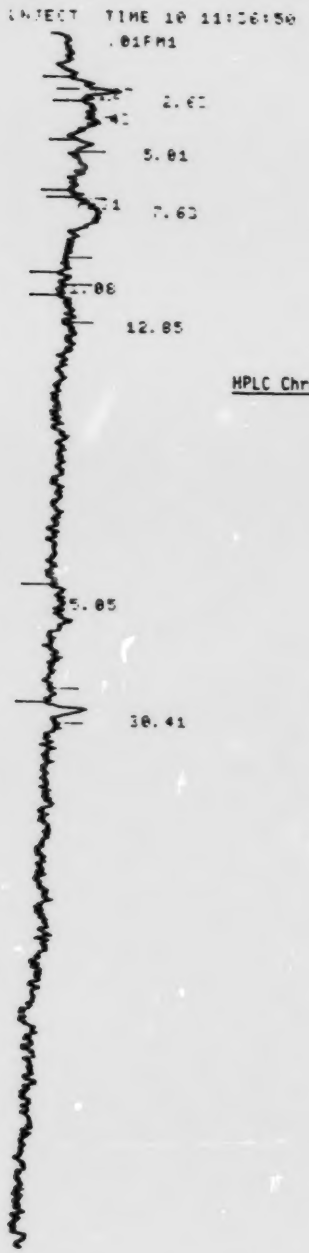


FIGURE 3

HPLC Chromatogram of PUF Extract - Last Extract of Second Set

(HPLC Conditions same as Fig. 1)

FIGURE 4

HPLC Chromatogram of PUF Extract - Third Set

(HPLC Conditions same as Fig.1)

FIGURE 5

HPLC Chromatogram of PUF Extract - Fourth Set

(HPLC Conditions same as Fig. 1)

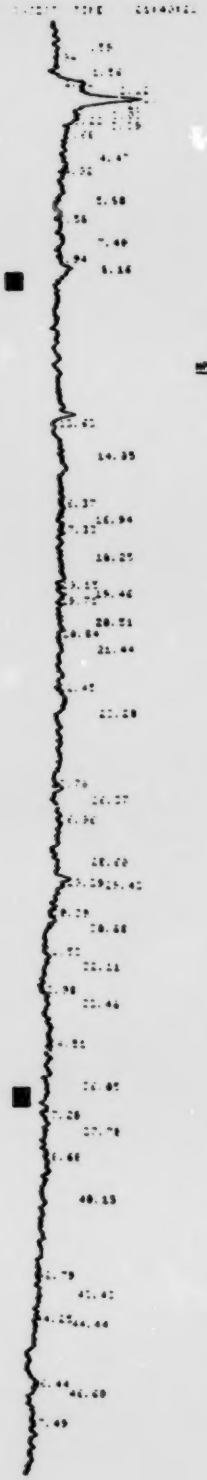


FIGURE 6

HPLC Chromatogram of XAD-2 Resin Extract

(HPLC Conditions same as Fig. 1)

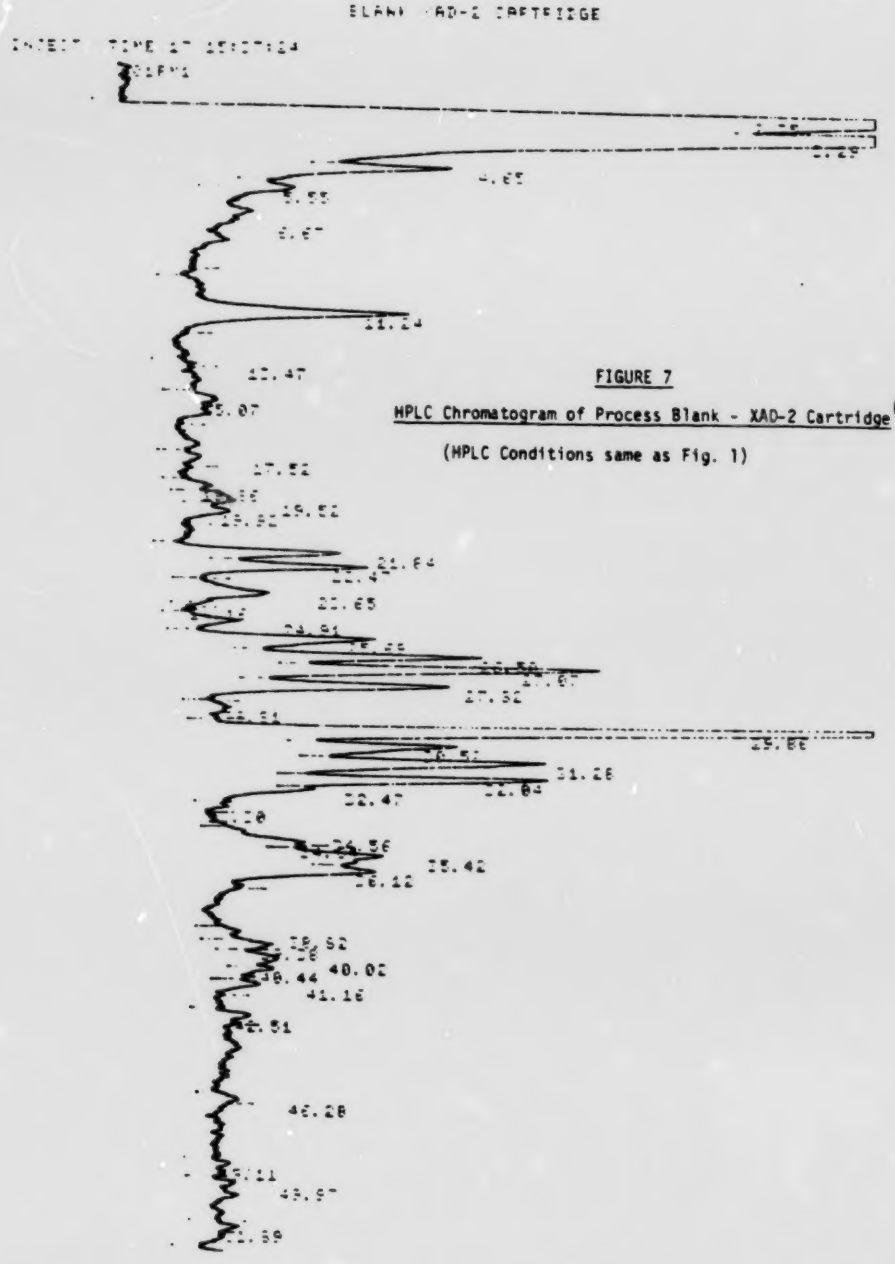


FIGURE 7

HPLC Chromatogram of Process Blank - XAD-2 Cartridge

(HPLC Conditions same as Fig. 1)

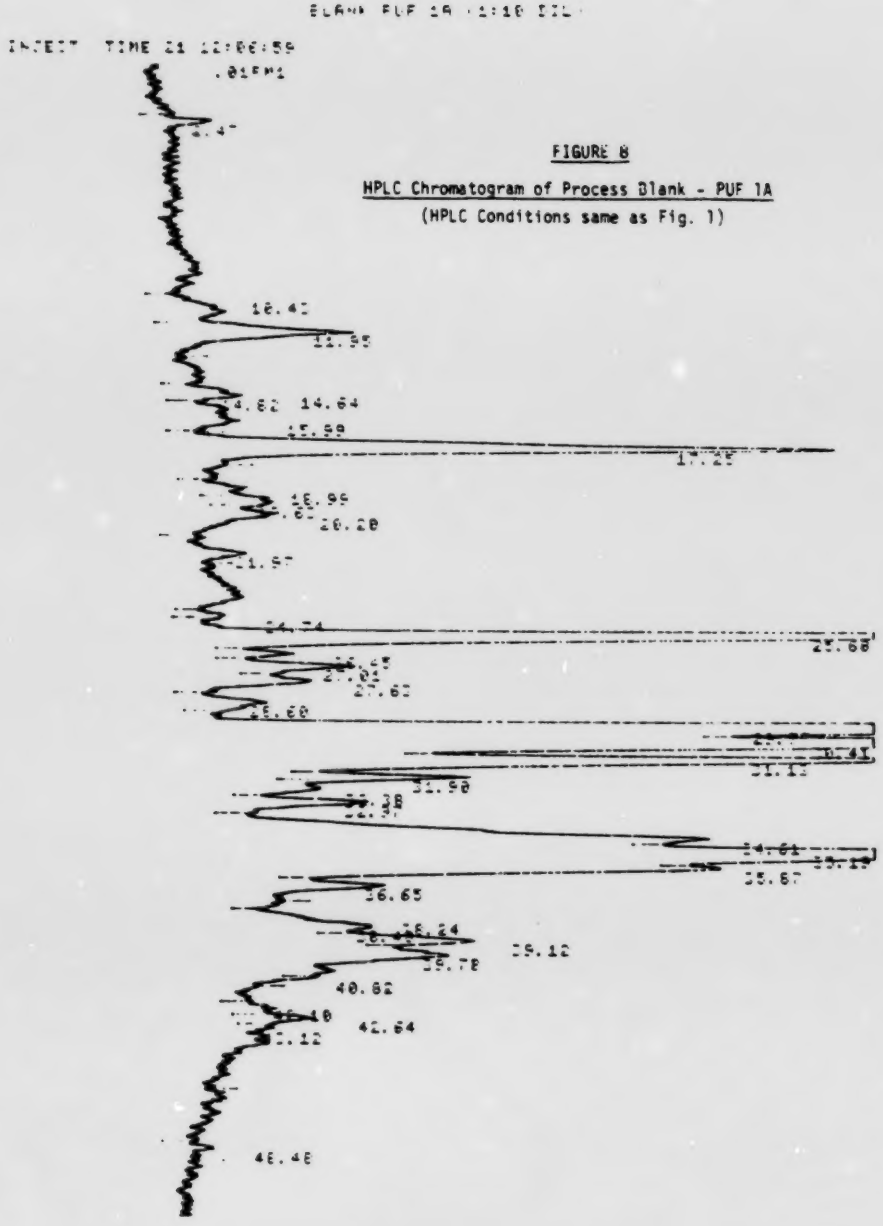


FIGURE 8

HPLC Chromatogram of Process Blank - PUF 1A

(HPLC Conditions same as Fig. 1)

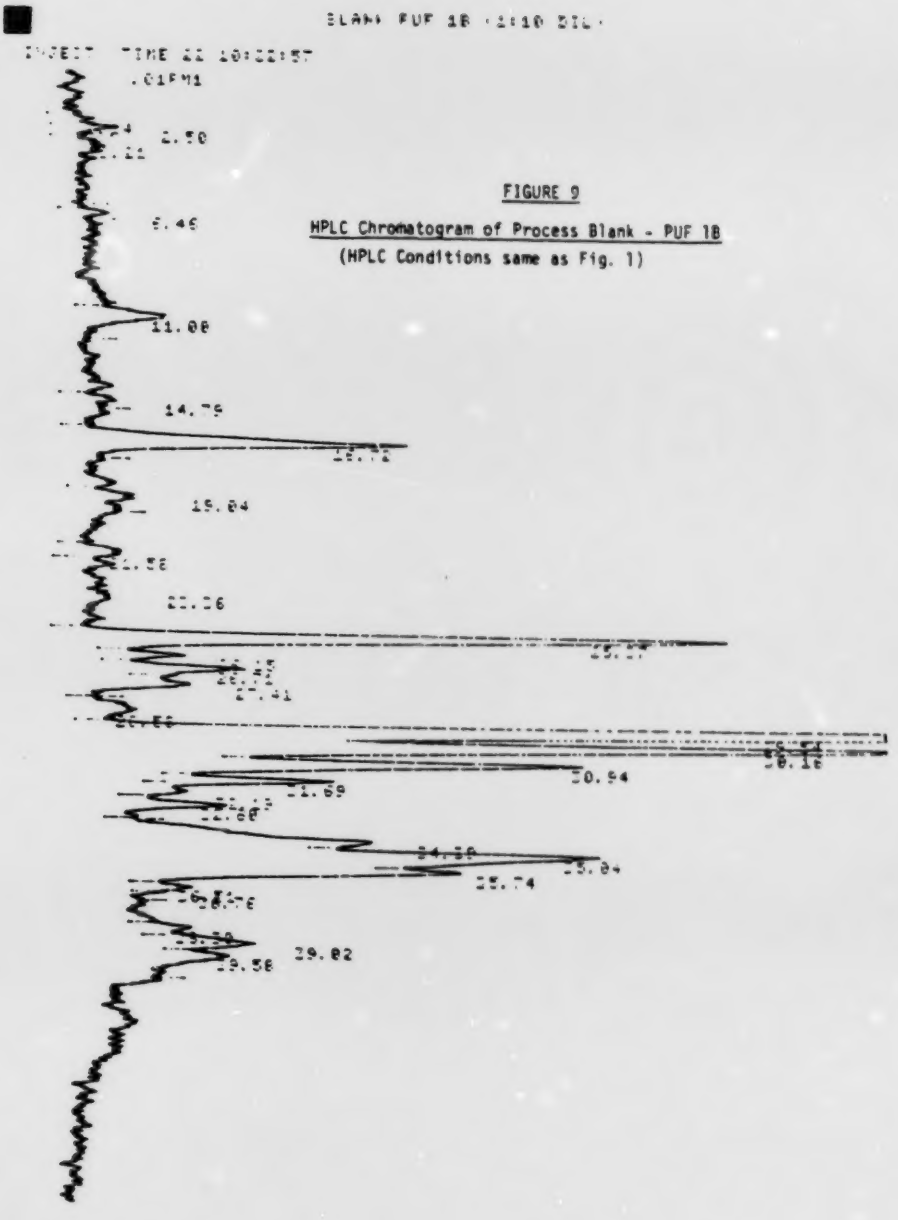


FIGURE 9

HPLC Chromatogram of Process Blank - PUF 1B

(HPLC Conditions same as Fig. 1)

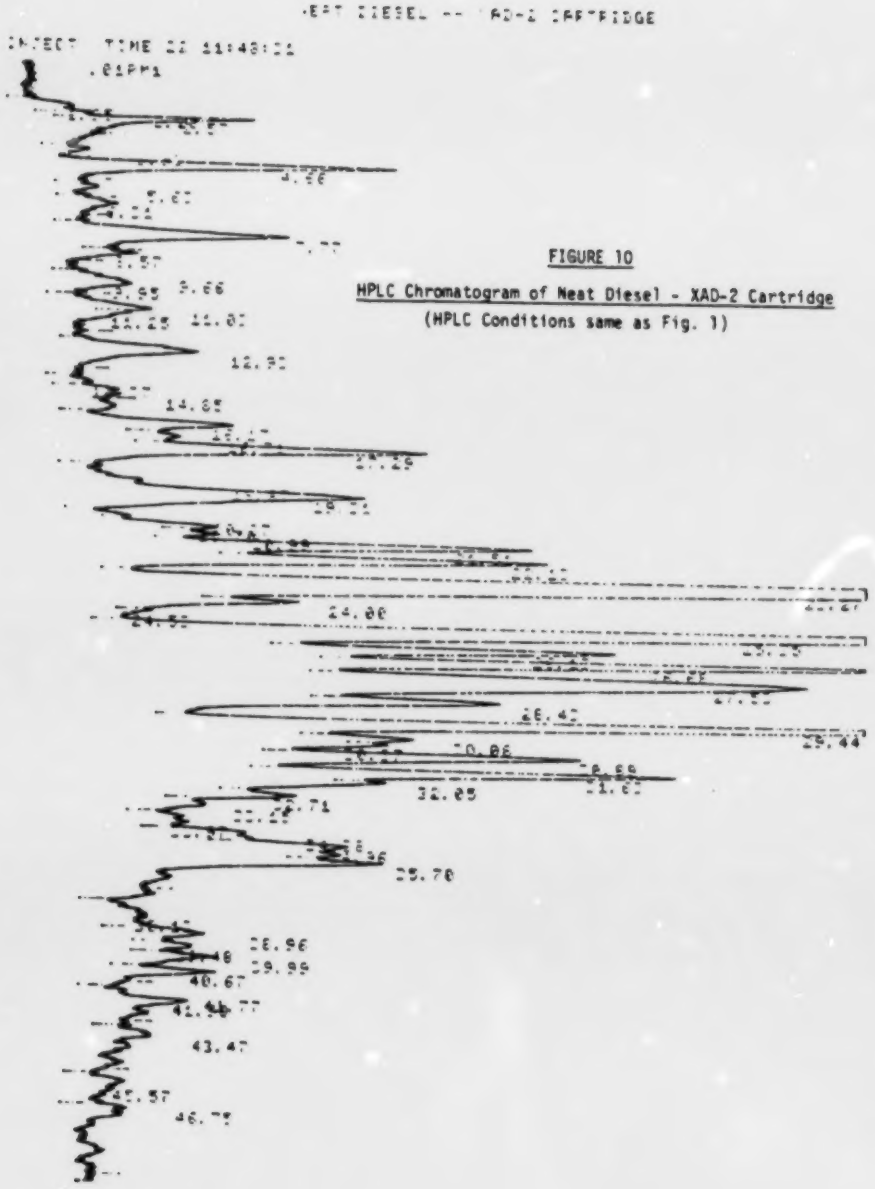


FIGURE 10

HPLC Chromatogram of Neat Diesel - XAD-2 Cartridge

(HPLC Conditions same as Fig. 1)

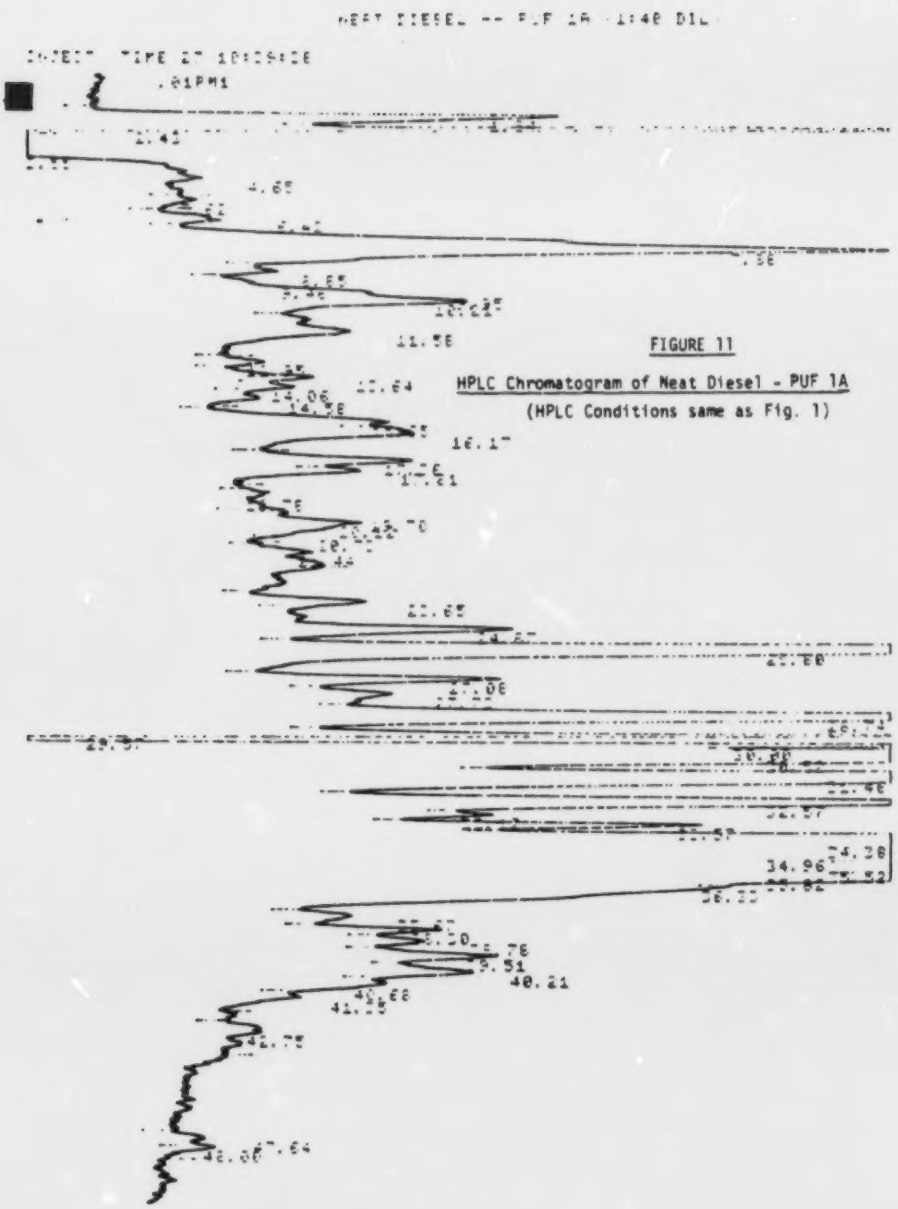


FIGURE 11

HPLC Chromatogram of Neat Diesel - PUF 1A

(HPLC Conditions same as Fig. 1)

FIGURE 12

HPLC Chromatogram of Neat Diesel - PUF 1B

(HPLC Conditions same as Fig. 1)

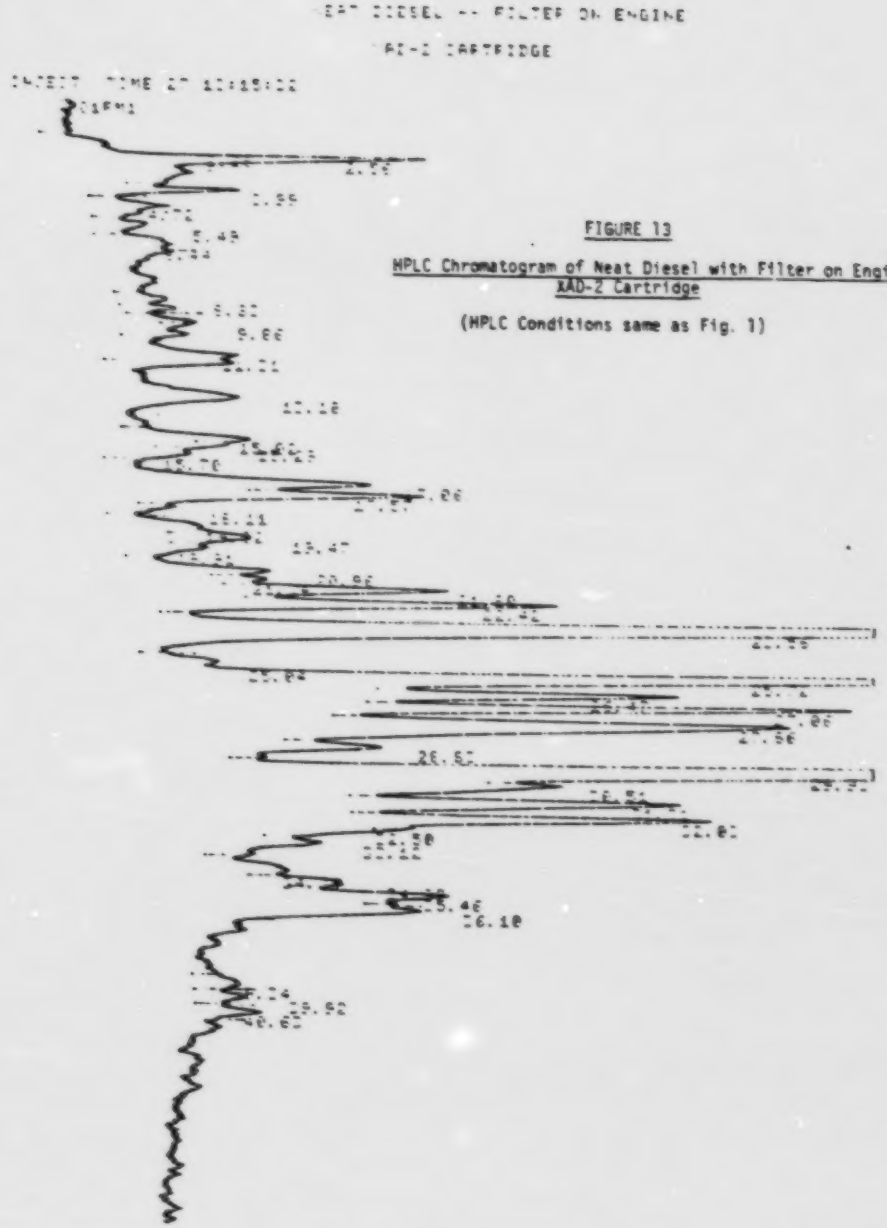


FIGURE 13

HPLC Chromatogram of Neat Diesel with Filter on Engine
XAD-2 Cartridge

(HPLC Conditions same as Fig. 1)

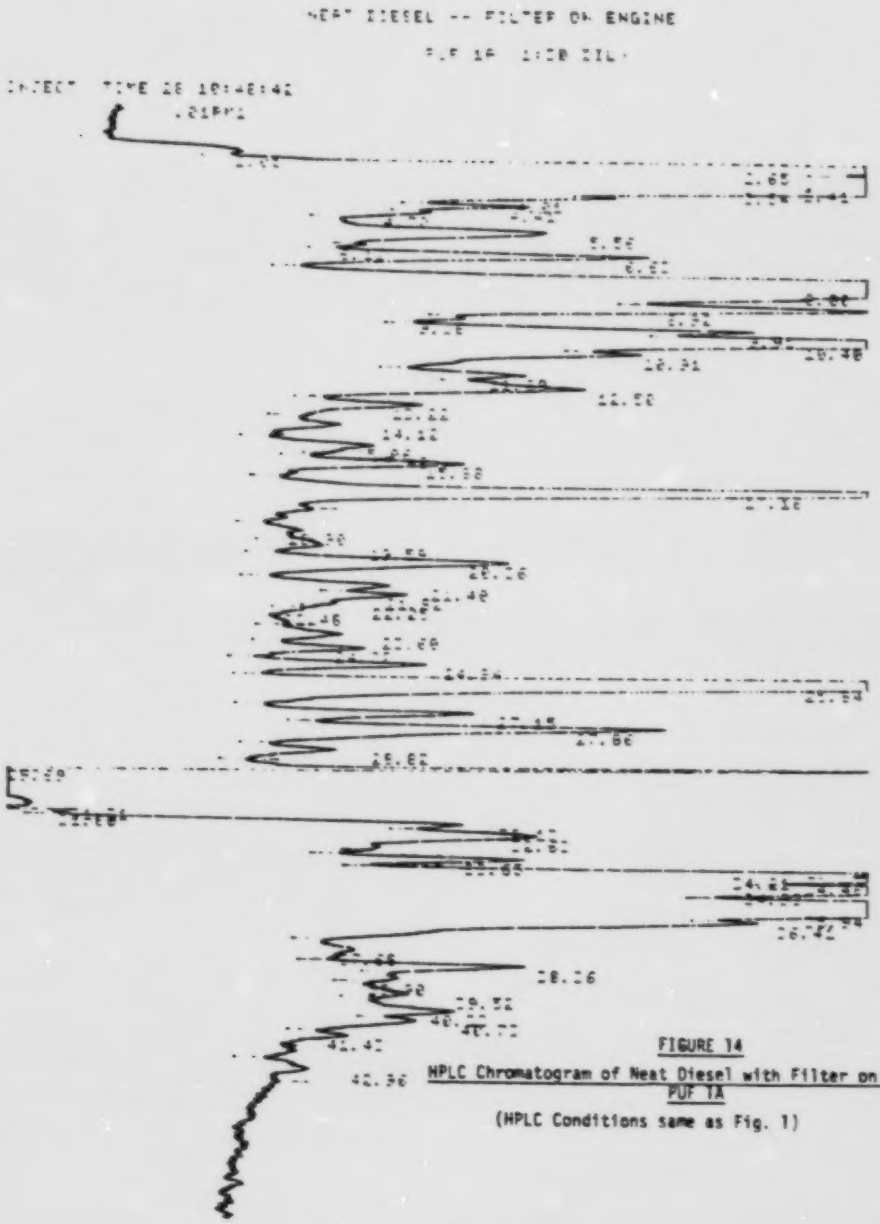


FIGURE 14

HPLC Chromatogram of Neat Diesel with Filter on Engine PUF 1A

(HPLC Conditions same as Fig. 1)

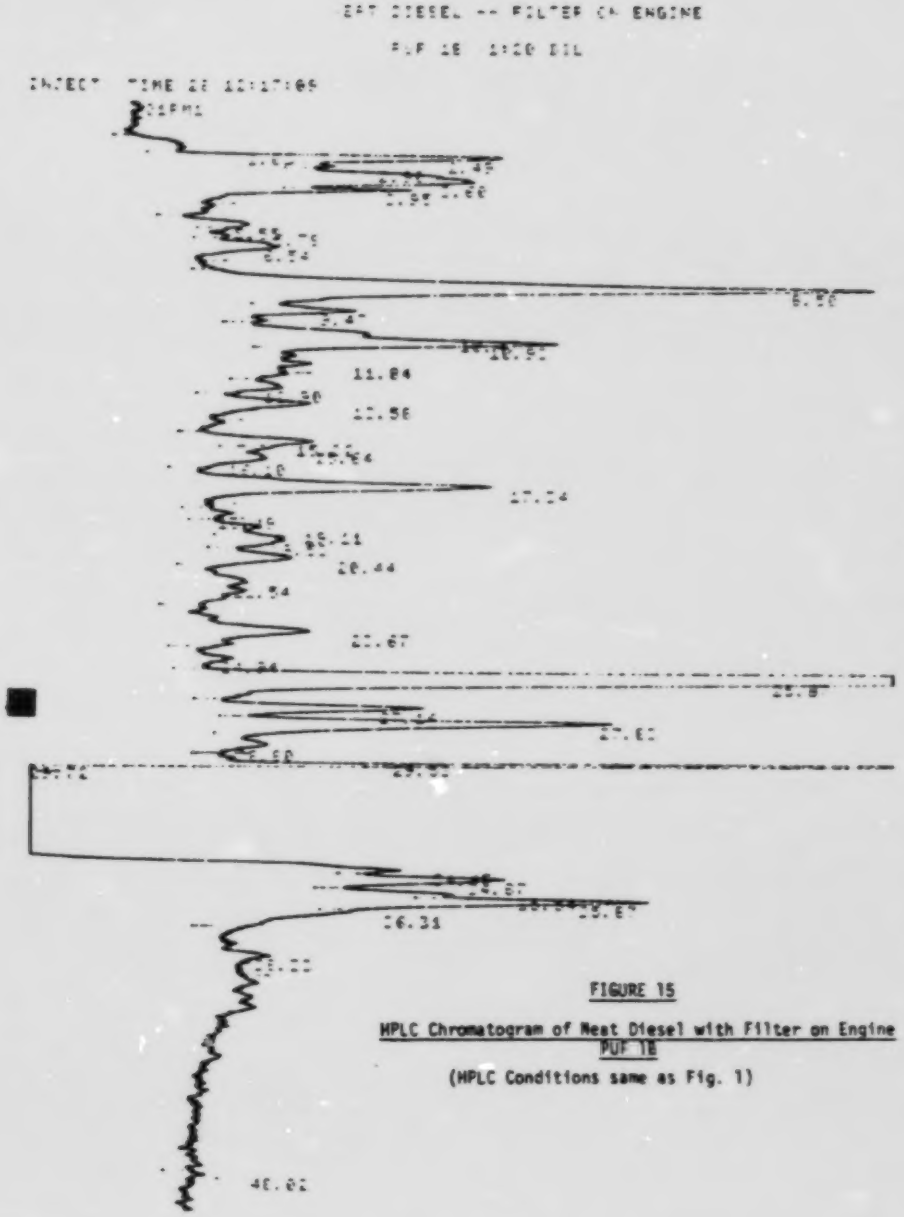


FIGURE 15

HPLC Chromatogram of Neat Diesel with Filter on Engine
PUF 18

(HPLC Conditions same as Fig. 1)